Haiying Qi
Bo Zhao
Editors

Cleaner Combustion and Sustainable World

Proceedings of the 7th International Symposium on Coal Combustion

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With 1260 figures

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Preface

The International Symposium on Coal Combustion (ISCC) which has been organized by Tsinghua University of China since 1987 has become an important academic event every four years.

As one of the 100 academic activities of Tshinghua University during her Centenary Celebration, the 7th Symposium, co-hosted by the Institute of Thermal Engineering of Tsinghua University and the Combustion Engineering Research Institute of Harbin Institute of Technology, was held successfully in Harbin, China, in July 17-20, 2011. In the background of energy crisis, global warming and the urgently needs for low-carbon energy technology, the symposium was of important significance.

The symposium covered the latest research and application results from academia and industry regarding to coal combustion, conversion and utilization. What's new was that besides conventional themes, people have paid more attention to application of ultra-supercritical (USC) technology in coal-fired power plants, energy conversion from biomass and coal, as well as coal's biggest challenge–CCS.

The symposium reached an unprecedented level in the scale and the extent of people's participation. The renewed International Advisory Committee consists of 52 well-known scholars and experts from 17 countries (22 Chinese and 30 foreigners). After review and selection, 218 technical papers divided into 143 oral presentations and 75 posters were accepted. 256 delegates attended the symposium from 14 countries, including USA, Germany, UK, Canada, Japan, Korea, Australia, Russia, Denmark, Switzerland, Sweden, Poland etc. Compared to previous symposiums, more industrial colleagues were present with high interests. Nearly 30 domestic and foreign research institutions, universities, foundations as well as enterprises as sponsors or co-sponsors provided their supports to the symposium.

The proceedings of the 7th ISCC collect 9 invited plenary speeches (partially in abstracts or slide shows) and 188 technical papers presented orally and in poster. These papers are divided into the following sections including the number of papers.

- Basic Coal Quality and Combustion / 37
- Emission Control / 40
- Fluidized Bed Combustion / 20
- Industrial Applications and Coal Use / 27
- Pulverized Coal Combustion / 27
- Carbon Dioxide Capture and Storage (CCS) /37

The proceedings can serve as a platform to exchange information and ideas for scientists, engineers, graduate students, equipment manufactures and operators, as well as technical managers who are working on coal combustion and conversion in energy and power generation areas.

We would like to acknowledge our members of the International Advisory Committee who devoted their time and energy to review the manuscripts, and to express our appreciation to Dr. Qiang Li of Tsinghua University Press for his effort in publishing the proceedings.

Haiying Qi, Bo Zhao

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Invited Plenary Speeches

Coal and Clean Coal Technology: Challenges and Opportunities

Andrew Minchener

Principal Associate, IEA Clean Coal Centre

Abstract

Globally, there is a growing concern about fuel diversity and security of supply, particularly with regard to oil and natural gas. In contrast, coal is available from a much wider range of sources and has greater price stability. Consequently, coal use is increasing rapidly, and by 2030 may well reach a level of more than 4,500 Mtoe, corresponding to close to a doubling of current levels. However, at the same time, tightening regulations will require better solutions for achieving environmental compliance, for which coal has a number of key issues to address. Most of the coal will be used in the power generation sector. Consequently, the key research challenges are to develop and deploy methods by which coal can be used cleanly, efficiently, and in a sustainable way. These include improvements to existing coal utilisation technologies, particularly to improve operational flexibility and availability, while reducing energy use through higher efficiencies. There is an increasing need to ensure improved emissions control, with the emphasis on achieving ever-lower emissions of particulates, SO_2 and NOx while also introducing control of trace species, particularly mercury. Alongside this, a key challenge is the integration of techniques that can capture CO_2 then transport and store it within secure geological formations, thereby resulting in near zero emissions of CO_2. From a power plant perspective, the need is to achieve such integration while minimising any adverse impact on power plant efficiency, performance of existing emissions control systems, operational flexibility and availability. At the same time, means to minimize the additional costs associated with such technology must be established.

Keywords: clean coal technology, CO_2 capture and storage, strategic initiatives, barriers to deployment

1. Global coal use and future projections

In 2009, in its annual projection of global energy use, the International Energy Agency (IEA) presented a reference (business as usual) scenario together with alternatives dependent on the application of various polices and market instruments. The reference case suggested that global energy use would rise from 12,000 Mtoe in 2010 to close to 18,000 Mtoe by 2030 (IEA 2009a). Coal showed by far the biggest increase, followed by gas then oil (Figure 1).

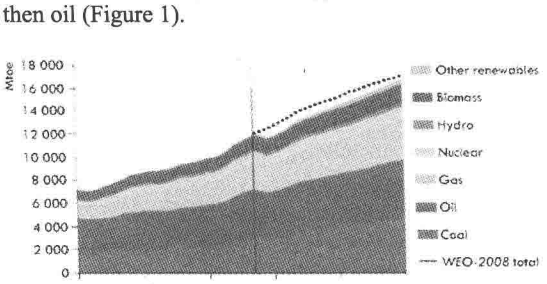

Fig. 1 Cumulative primary energy demand-IEA reference scenario (IEA 2009a)

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The main drive for increased coal and gas use would be in power generation, with coal use in that sector rising by three percentage points to 44% in 2030. However, the increase in energy demand would not be uniform since China and India would represent over 53% of incremental primary energy demand, while for coal over 80% of the growth would be in non-OECD countries (IEA 2009a).

The IEA has stressed that such an energy pathway has significant adverse implications for environmental protection, energy security and economic development, due to man-made climate change concerns, with annual CO_2 emissions predicted to rise from 28.8 Gt in 2007 to 34.5 Gt in 2020 and 40.2 Gt in 2030. Consequently, the IEA produced an alternative low-carbon energy future scenario, which would result in any global temperature rise being limited to 2℃ where the greenhouse gas concentration would be stabilised at around 450 ppm CO_2-equivalent.

The aim would be to massively improve end-use efficiency, ensure early retirement of old, inefficient coal plants and their replacement by more efficient units, many of which would be fitted with carbon capture and storage (CCS), increased deployment of renewables, plus nuclear power (IEA 2009b). The potential impacts of the various actions are shown in Figure 2. This shows that low-carbon technologies could deliver a significantly different future and that CCS could have a potentially significant role to play, providing the remaining technical and economic barriers to its commercial deployment can be addressed successfully.

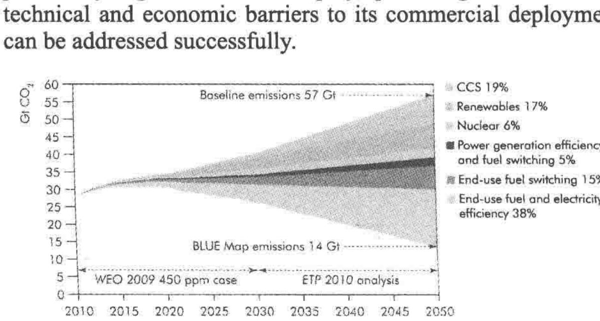

Fig. 2 Potential CO_2 emissions reduction through to 2050 (IEA 2010)

Future coal demand through to 2030 and 2050 is likely to lie somewhere between these two IEA projections since, as yet, there is no global agreement on the appropriate way forward. However, many countries are taking steps to reposition their energy portfolios and there are significant activities to introduce various energy saving initiatives, including the development of techniques to reduce CO_2 emissions in absolute terms. It is evident that the major coal using nations must all be engaged in this global initiative if it is to be successful.

2. Future requirements for coal utilisation technologies

Coal will remain attractive to stakeholders providing that it can be used efficiently and with reduced environmental impact, with polices and tightening regulations being applied to ensure appropriate compliance. The need is to enhance the appropriate coal-based technologies through efficiency and environmental improvements plus lower costs compared with the existing options. At the same time, such an approach will provide the framework on which the related near-zero emissions technologies can be established in a cost effective, credible manner.

Outside of the power sector, there is a still significant use of coal in the iron and steel industry and the cement sector, where there is a complementary need to address the environmental challenges together with ensuring sustainable costs reduction. In due course, the possible introduction of CCS will need to be considered.

2.1 Advanced supercritical coal fired power plants

Globally, pulverized coal (PC) fired power plants are the coal based technology of choice, with considerable advances having been made in recent years to establish supercritical and ultrasupercritical designs. The state of the art efficiency in Europe is >45% (net, LHV basis), for a plant operating with supercritical steam temperatures of about 600℃, with plants having been installed in Denmark, Italy and Germany. Also, techniques have been established to control particulate emissions and acid gas pollutants such as NO_x and SO_2. Globally, the major market is in China where some 450 GWe of supercritical and ultra-supercritical power plants are either operational, under construction or at the design stage (Mao 2011). Unit sizes are operational up to 1000 MWe while designs are underway for 1320 MWe units.

There is scope to further improve the competitiveness of PC technology with an ongoing need to reduce costs, increase efficiency and environmental performance while improving flexibility of operation and maintaining high availability, including the ability to utilize alternative fuels in combination with coal. The challenge is to establish an overall engineering design that can achieve the required efficiency while maintaining fuel and operational flexibility in a cost competitive manner (Coal Research Forum 2011). There is a need to:

- Optimise cycles, with higher performance steam turbines, including better utilization of waste heat.
- Develop, select and fabricate materials to ensure progressive increases in steam temperature and pressure towards 700℃ and 35 MPa, while ensuring that novel components using new materials of construction can achieve acceptable reliability and economic cost. It is essential that the higher costs of these new materials can be offset by establishing a compact design of boiler to minimise the need for the very expensive heat transfer materials. This requires a change of design for furnace walls, the re-location of the heat transfer surfaces, a change to the overall plant concept including the location of the turbine headers closer to the steam turbine. It is stressed that the designers must ensure that the overall cost/benefit analyses are commercially attractive. This requires significant innovation, both in the design of individual components and in the integration of the complete power plant concept.
- Improve multi-pollutant control, ensuring adequate interaction of individual components, leading to optimum combinations of technologies that ensure compliance with present and future emission regulations. Linked to this is the need to determine the impact of any new pollutant control systems on the usability and marketability of the various by-products arising from the power plant.
- Improve flexibility of operation and control, with the need to establish the optimum compromise between efficiency and operability, through dynamic modelling, control and instrumentation development, as well as assessment of the impact of rate of change on the integrity of materials and welds.
- As well as operational flexibility, greater fuel flexibility will be required and there is a need to improve the capability to cofire coal with either biomass or other organic wastes, with indications that up to 25% energy input by biomass might be effective compared to the lower levels (~5%) currently utilised. This must be achieved while minimizing adverse impacts due to furnace corrosion, slagging and fouling and impact on NOx reduction catalysts for the full range of coals and alternative feedstock combinations. This should include all aspects of the biomass/wastes chain, such as efficient preparation and processing of sustainable feedstocks, understanding of materials issues.

2.2 Coal gasification based power plant

IGCC is a technology that offers the prospect of very low conventional emissions from coal based power plant while also achieving higher cycle efficiencies through ongoing improvements to gas turbine technology. However, to date, this potential has not been realised due to major concerns with higher capital costs and lower levels of reliability and availability, compared to advanced PC plant. To put that in context, there are only a few coal based IGCC demonstration plants operational at modest efficiencies of 41-43%, although there is a demonstration unit being built in China and various early stage plans for projects in Europe and the USA.

Various studies have shown that IGCC could achieve much higher efficiencies than those of the current demonstration plants by implementing fairly simple design changes based on conventional and available technology (European Commission 2004). However, the reality is that the technology needs to show acceptable component reliability and cycle availability. Engineering design issues will include the need to establish IGCC power plants with improved feeding systems, particularly for mixed feedstocks, improved firetube cooler designs with regard to minimising deposition and corrosion, selection of materials to ensure greater reliability, especially refractories, dry units for dust removal, sulphur removal and alkali/trace metals control, together with lower cost ASUs.

In terms of the overall development needs, the primary aim is to establish adequate performance and availability such that generating companies can have confidence that it is a commercially viable technology. The subsequent aim is to reduce costs, increase efficiency and improve flexibility of operation, including the ability to utilize alternative fuels in combination with coal. Such work would include:

- Optimisation of cycles through utilisation of waste heat and with as much integration as possible of the various components to ensure a lower system capital cost without adversely affecting availability.
- Establishment of hot gas cleaning improvements for pollutant removal at elevated temperatures. This needs to include the development of more robust systems, with integrated higher efficiency syngas cooling, capable of removing all pollutants.
- Inclusion of advanced gas turbines into the cycle, to fire the fuel gases that will arise from different gasification units, particularly hydrogen, which will be the prime fuel produced when CO_2 capture is undertaken. This will require materials development and selection, development of fabrication techniques and blade cooling technologies.
- Improved fuel flexibility to allow for co-use of alternative fuels, such as biomass and waste, in applications where the economics are favourable. This includes the development of improved feeding and handling systems capable of use for all viable feedstock combinations.
- Development of a more cost effective air separation process.

2.3 Non-power uses of coal

The R&D needs in these sectors mirror to a degree those in the power generation sector. Thus there is a need to improve the overall performance and cost effectiveness of existing units while also seeking ways to advance the technology to ensure future environmental compliance, including minimising CO_2 emissions by capture.